$$\begin{aligned}\lambda(i,N,P) &= \min_{\varphi}\left\{\sum_{j=0}^{N-1}\left|r(i+j)-r(i+j+P)e^{j\varphi}\right|^2\right\}\\ &= \min_{\varphi}\left\{\sum_{j=0}^{N-1}\left|r(i+j)\right|^2+\left|r(i+j+P)\right|^2-2\mathrm{Re}\left\{r(i+j)r^*(i+j+P)e^{-j\varphi}\right\}\right\}\\ &= \sum_{j=0}^{N-1}\left[\left|r(i+j)\right|^2+\left|r(i+j+P)\right|^2\right]-2\left|\sum_{j=0}^{N-1}r(i+j)r^*(i+j+P)\right|\\ &= E(i,N,P)-2\left|w(i,N,P)\right|\end{aligned}$$

The criterion for the beginning of the block is indicated by the index i, at which the metrics have their minimal phase:

$$i_{start} = \arg\min_{i} \lambda(i,N,P)$$

The block synchronization in the OFDM system should, on the basis of the periodic preamble, indicate the interference-free range of the subsequent data blocks. To that end, the correlation window is shortened relative to the sequence length by the length of the guard interval.

This method described above is actually used for coarse block synchronization. In principle, it therefore offers only quite imprecise results, in terms of both fine block estimation and frequency estimation.

The transmitter S of Fig. 1 inserts a special synchronization train, especially at the beginning of transmission, into the data stream; in the receiver, this sequence serves to estimate the chronological position of the signal to be received, and/or to estimate the center frequency error between the transmitter and the receiver. The synchronization train is formed according to the invention as follows:

- two different symbol sequences A and B of the same

length L_1 with ideally favorable autocorrelation properties are selected. In the case of OFDM, these can be OFDM symbols, which have the same length as or a different length from a normal data symbol;

- the two symbol sequences A and B are always transmitted in such a way that in alternation, A is transmitted twice and B is transmitted twice, as in Fig. 3. The indexes for the symbol sequences A and B indicate the occurrence of the trains A and B.

The chronological position of the signal to be received between the transmitter S and receiver E is ascertained from a composite term, in particular the total metrics, of the various symbol sequences, in this case the pairs of symbol sequences, within a predetermined interval.

Then in the receiver the total metrics λ_S, from the sum of individual metrics λ over all the identical sequence pairs (A_I, A_m) and (B_I, B_m), where $1 \leq 1$, $m \leq M$ and $m >$, become the following:

$$\lambda_S(i) = \sum_{(A_l,A_m)\in M_A} \lambda(i+S(A_l,A_m),L_1,\Delta(A_l,A_m)) + \sum_{(B_l,B_m)\in M_B} \lambda(i+S(B_l,B_m),L_1,\Delta(B_l,B_m))$$

In this equation, S (X,Y) designates the relative starting index for the signal interval X, and Δ (X,Y) designates the spacing between the two pairs of signals X,Y.

Whichever index i_{start} that minimizes the metrics λ_S within an interval I_{RS} predetermined by the frame synchronization is selected as the beginning of the block:

$$i_{start} = \arg\min_{i \in J_M} \lambda_S(i)$$

In the frequency estimation, the problem arises that the phase rotation between two identical symbols (A_1, A_m) and (B_1, B_m) can exceed 360°, so that the resultant multivalence must first be solved. As the reference frequency fref for this, the estimated frequency position f_o from the phase rotation $\hat{\phi}_{01}$

of two adjacent periodic segments each must be used, since here the capture range, where $|f_o\| < f_a / (\pi L_1)$ is greatest:

$$f_{ref} = \hat{f}_{o1} = \frac{f_a \cdot \hat{\varphi}_{o1}}{2\pi L_1}$$

where

$$\hat{\varphi}_{o1} = \arg\left\{ \sum_{l=1,3,5,\ldots}^{N-1} w(i_{start} + S(A_l, A_{l+1}), L_1, L_1) + w(i_{start} + S(B_l, B_{l+1}), L_1, L_1) \right\}.$$

To achieve the most secure possible frequency estimation, once again the phase rotations for all the other pairs of intervals (A_1, A_m) and (B_1, B_m) must be taken into account. Let $M_{A\delta} \subset M_A$ and $M_{b\delta} \subset M_B$ be the set of all the pairs (A_1, A_m) and (B_1, B_m) with the same spacing $\Delta(A_1, A_m)$ and $\Delta(B_1, B_m)$, and let δ_{max} be the number of different sets $M_{A/B\delta 1/}$, then the overall result for the estimated value of the center frequency error f_0 is:

$$\hat{f}_o = \sum_{\delta=1}^{\delta_{max}} c_\delta \cdot \hat{f}_{o\delta} = \sum_{\delta=1}^{\delta_{max}} c_\delta \frac{f_a \cdot \hat{\varphi}_{o\delta} \cdot e^{-jV(\hat{\varphi}_{o1}, \hat{\varphi}_{o\delta})}}{2\pi\delta(A_l, A_m \equiv M_{A\delta})}$$

where

$$\hat{\varphi}_{o\delta} = \arg\left\{ \sum_{(A_l, A_l) \in M_{A,\delta}} w(i_{start} + S(A_l, A_m), L_l, \Delta(A_l, A_m)) + \sum_{(B_l, B_l) \in M_{B,\delta}} w(i_{start} + S(B_l, B_m), L_l, \Delta(B_l, B_m)) \right\}$$

The coefficients c_δ are weighting factors, with which the different noise levels, which are superimposed on the estimated phase values, are taken into account. They result on the one hand from the number of sequence pairs that are taken into account and on the other from the spacing (X,Y) of the frequency pairs. The function [paste in, page 9, line 4] solves the multivalence of the phase [ditto, line 5] on the basis of the estimated phase value [ditto, line 6] ascertained beforehand.

According to the invention, the symbols indicated can also be used for channel estimation, if they are known in the transmitter and the receiver. To that end, the synchronization symbols, once the frequency correction has been done, are FFT-processed in the receiver, and the amplitude weights and phase weights of the individual subcarriers are determined. If the synchronizing signals (A and B) are shorter than a normal OFDM symbol, then the phase weights and amplitude weights of the subcarriers not transmitted must be ascertained by interpolation. The fact that a plurality of known synchronizing symbols are used can be exploited for the sake of averaging the channel parameters over the known symbols, so as to increase the accuracy of the channel estimation.

It should now be assumed that the transmitter places a preamble in accordance with Fig. 4 before each synchronization train. The synchronization train according to the invention is preceded by a preamble that serves to set the gain control of the receiver correctly, in order to fully modulate the analog-to-digital converter. The ensuing

synchronization symbol comprises the sequence AABBAA.

The metrics for the block synchronization in this case are calculated as follows:

$$\lambda_s(i) = \lambda(i, L_1, L_1) + \lambda(i, L_1, 4L_1) + \lambda(i, L_1, 5L_1) + \lambda(i + L_1, L_1, 3L_1) \\ + \lambda(i + L_1, L_1, 4L_1) + \lambda(i + 4L_1, L_1, L_1) + \lambda(i + 2L_1, L_1, L_1)$$

The individual metrics correspond to the pairs (A_1, A_2), (A_1, A_3), (A_1, A_4), (A_2, A_3), (A_2, A_4), (A_3, A_4), (B_1, B_2). The starting value for the block is:

$$i_{start} = \arg\min_i \lambda_S(i)$$

For the frequency synchronization, the center frequency error f_0 is calculated as follows:

$$\hat{\varphi}_{01} = \arg\{w(i_{start}, L_1, L_1) + w(i_{start} + 2L_1, L_1, L_1) + w(i_{start} + 4L_1, L_1, L_1)\},$$

$$\hat{\varphi}_{02} = \arg\{w(i_{start}, L_1, 4L_1) + w(i_{start} + L_1, L_1, 4L_1)\}$$

$$\hat{f}_0 = \frac{f_a}{2\pi}\left(c_1 \frac{\hat{\varphi}_{01}}{L_1} + c_2 \frac{\hat{\varphi}_{02} e^{-jr(\hat{\varphi}_{01}, \hat{\varphi}_{02})}}{4L_1}\right).$$

One possible realization of the transmitter is shown in Fig. 5. An OFDM transmitter, that is, its coding and modulating device CM, is supplied with a bit train. The usual processing by IFFT (Inverse Fast Fourier Transformation), parallel-serial conversion P/S, and the insertion of the guard interval SI follows by periodic continuation (see source [1]). Next, at the beginning of each transmission, the synchronization train is read out of a memory SP and inserted, together with the preamble of Fig. 4,

change as follows:

$$\lambda_S(i) = \lambda(i, L_1, L_1) + \lambda(i, L_1, 4L_1) + \lambda(i + L_1, L_1, 4L_1) + \lambda(i + 4L_1, L_1, L_1) + \lambda(i + 2L_1, L_1, L_1)$$

The individual metrics would in this case correspond to the pairs (A_1, A_2), (A_1, A_3), (A_2, A_4), (A_3, A_4), (B_1, B_2).

It is equally possible in the method for calculating the center frequency error to use only some of the possible angle errors in calculating the equation for Φ_{06}.

- Under some circumstances, it is favorable to insert guard intervals before the individual frequency pairs. If S is a guard interval of arbitrary length (in general, the periodic continuation of a symbol), the result is thus for example the train SAASBBSAA. The calculation prescriptions described above logically apply, and the guard intervals are not evaluated.

- By the method described above, the signal trains A and B are each transmitted in pairs a plurality of times in succession. The method for block and frequency synchronization can be analogously used if the signal trains occur individually one after the other, such as the train ABAB. It is equally possible for the trains A and B not be inserted in pairs but each more than twice. One example of a train for a triple occurrence each time would be AAABBBAAA. The calculation prescriptions given above logically apply.

It is furthermore possible to use more than two different signal trains, such as three different signal trains A, B and C. The rule in this case would be that at least one signal train is put together as a pair, with a